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Abstract: Sudden and gradual land use changes can result in different socio-ecological systems, sometimes referred to as regime shifts. The Lao PDR (Laos) has been reported to show early signs of such regime shifts in land systems with potentially major socio-ecological implications. However, given the complex mosaic of different land systems, including shifting cultivation, such changes are not easily assessed using traditional land cover data. Moreover, regime shifts in land systems are difficult to simulate with traditional land cover modelling approaches. A novel simulation approach was employed that focused on simulating changes in land systems rather than focusing on land cover. With the CLUondo model we simulated three scenarios of potential developments between the years 2010 and 2030 assuming different degrees of international market integration and sustainable growth objectives. Although all scenarios show a decline of shifting cultivation systems, the respective orientation of markets and land governance resulted in strongly different land change trajectories. The land system changes are strongly location dependent and different trajectories are found in different parts of the country. Some scenarios show clear elements of land sparing with intensification of land management in the valleys and re-growth of forest on sloping land. Other scenarios show elements of enhanced multi-functionality. The approach addressed methodological challenges in simulating land system regime shifts and complex mosaic landscapes while accounting for societal demands for different types of goods and services from land systems. The land systems approach allows a nuanced representation of different types of forests and agricultural systems such as shifting cultivation and commercial agricultural plantations. Simulation results contribute to a debate about desired future land use on the national scale including its environmental and socio-economic implications.

# Scenarios of land system change in the Lao PDR: transitions in response to alternative demands on goods and services provided by the land

## Authors

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## Abstract

Sudden and gradual land use changes can result in different socio-ecological systems, sometimes referred to as regime shifts. The Lao PDR (Laos) has been reported to show early signs of such regime shifts in land systems with potentially major socio-ecological implications. However, given the complex mosaic of different land systems, including shifting cultivation, such changes are not easily assessed using traditional land cover data. Moreover, regime shifts in land systems are difficult to simulate with traditional land cover modelling approaches. A novel simulation approach was employed that focused on simulating changes in land systems rather than focusing on land cover. With the CLUondo model we simulated three scenarios of potential developments between the years 2010 and 2030 assuming different degrees of international market integration and sustainable growth objectives. Although all scenarios show a decline of shifting cultivation systems, the respective orientation of markets and land governance resulted in strongly different land change trajectories. The land system changes are strongly location dependent and different trajectories are found in different parts of the country. Some scenarios show clear elements of land sparing with intensification of land management in the valleys and re-growth of forest on sloping land. Other scenarios show elements of enhanced multi-functionality. The approach addressed methodological challenges in simulating land system regime shifts and complex mosaic landscapes while accounting for societal demands for different types of goods and services from land systems. The land systems approach allows a nuanced representation of different types of forests and agricultural systems such as shifting cultivation and commercial agricultural plantations. Simulation results contribute to a debate about desired future land use on the national scale including its environmental and socio-economic implications.

**Keywords:** Land use change; land system; regime-shifts; agricultural intensification; modeling; shifting cultivation;

## 1. Introduction

The world population is facing the challenge to manage trade-offs between satisfying human needs on the short term while maintaining the ability of the biosphere to provide goods and services in the long run (Foley et al., 2005). Land, as a fundamental resource for production of food, fuel and fibre, is likely to face many changes as a result of competing claims for goods and services. In the Lao PDR (hereafter called Laos) shifting cultivation (also called swidden, slash and burn) is a century-old, extensive form of land use dominating approximately half of the agriculturally used land in the country (Messerli et al., 2009). Shifting cultivation includes the temporary agricultural use of forested land followed by a fallow period leading to re-growth of forest in different succession stages. Characteristic for this land use is the emergence of various habitats that co-exist in small-scale spatial configurations. It is, however, also controversial and widely debated as one of the drivers of deforestation and forest degradation (Vongvisouk et al., 2014). With the onset of rigorous reforms of the New Economic Mechanism NEM in the years 1985 to 1986 (Otani et al., 1996; Rigg, 2009), a shift towards different land uses began in Laos. The belief that agricultural intensification will spur economic growth along with efforts to conserve Laos' biogeographical regions that are rich in biodiversity contributed to a decrease of shifting cultivation. In the 1990s the government started to establish a system of conservation areas that up to date reached a number of 24 National Protected Areas (NPA) (formerly National Biodiversity Conservation Areas) including two corridors, altogether making up more than 15% of the total land area in 2010 (MAF, 2010; DOF 2011). Furthermore, the government promoted and facilitated permanent agriculture by issuing land titles to smallholders (Rigg, 2005) and granting concessions for plantations to investors at a sharply increased rate since the early 2000s (Schönweger et al., 2012).

Laos' switch from a dominance of shifting cultivation towards a land-sparing strategy that separates intensive agriculture and forest conservation is in line with the trend in other South-East Asian nations such as Vietnam, Indonesia and southern China. In recent decades land use in those countries underwent transitions of a sudden, non-linear nature and of such magnitude as to result in a new land regime. Such regime shifts occur when socio-ecological systems fundamentally change their characteristics in terms of land use composition and ecosystem functions (Müller et al., 2014). Laos has not yet experienced a land regime shift comparable to the large changes in Vietnam, Indonesia and southern China, but, according to Müller et al. (2014), early warning signs for such a regime shift to come soon are signalled. Other scholars describe Laos as a country in the midst of an agrarian transition (Rigg, 2005) experiencing rapid change from smallholder farming to industrialized agriculture and plantations; co-evolving with a change in the economy from a subsistence-oriented to a market-oriented economy (Heinimann et al., 2013; Vongvisouk et al., 2014). These findings and the outlook towards the pressure to

improve livelihoods while managing the multiple interests to exploit its natural resources make Laos a very interesting case to study and explore possible future land use changes.

In recent years, several spatial and spatio-temporal assessments of land change have been carried out on different scales relevant to Laos. These include an assessment of land cover change for Montane Mainland South East Asia MMSEA on the regional level (Fox et al., 2012; Fox & Vogler, 2005; Leinenkugel et al., 2015) an inventory of land cover mosaics on the national level by Messerli et al. (2009), several assessments of shifting cultivation using remote sensing on the subnational level (Boillat et al., 2015; Hurni et al., 2013; Hurni, et al. 2012; Kamusoko et al., 2013; Liao et al., 2015) and effects of specific crops on landscapes and livelihoods on the local level (Evans et al., 2011). While the more local studies depict the agricultural transitions clearly, the transitions are not as evident from the large scale assessments as there is only a focus on land cover changes, ignoring the intricate changes in the land systems of which land cover change studies only provide a partial reflection (Schmidt-Vogt et al., 2009). Land cover representations in land use models often fail to capture the differences in intensity of land use and land management, especially when assumed that land systems are coupled-human-environmental systems consisting of a mosaic of land covers and land uses (Turner et al., 2013; Van Asselen & Verburg, 2013). Moreover, many of the existing studies have been providing an assessment of the current conditions, or an analysis of historic changes. Given the speed of transitions and to anticipate the possible trajectories of land change in the future, a national scale analysis of future transitions between land systems is required to explore the trade-offs of different development options including orientation towards short-term economic growth or long-term socio-economic growth (Mertz et al., 2009; Messerli et al., 2015).

To assess future land change under such conditions is challenging as regime shifts in land systems are difficult to simulate because of the unpredictability and complexity of the underlying drivers of land change (Müller et al., 2014) and the lack of data representing the land systems. As a result, most land change models are incapable of representing changes in land systems, especially when these relate to changes in management practices.

The aim of this study is to implement a modelling approach to represent land system changes in the context of Laos and simulate future transitions in land systems for three different scenarios. To address the challenge of capturing regime shifts of land systems in our simulations we have used a modelling environment that uses land systems as units of simulation rather than land cover types. These land systems are described as coupled socio-ecological systems that capture the dominant ecologic and socio-economic characteristics related to land use at the landscape level. Under that definition, both land cover and land management are seen as components that make up land systems (Van Asselen & Verburg, 2012). This definition allows us to distinguish shifting cultivation, smallholder permanent agriculture, large-scale commercial plantations and forest that have similar land cover but represent very different land uses.

In the next section we describe how the land systems have been determined and how changes were simulated. Based on the results of three different scenarios that capture alternate socio-economic development trajectories of the country we discuss the different possible future trajectories for land systems in Laos, but also relate this to global patterns of land system change and the ways in which we can use land system models to represent these changes.

## 2. Methods

### 2.1. Overall approach

We investigated land system transitions in Laos in three major steps. First, we established a spatially explicit representation of land systems by mapping agricultural and forest systems in Laos. This was achieved by integrating different datasets that provide complementary insights into the land systems: land cover maps, inventory maps of concessions and leases, and village level data on land use of an agricultural census. Secondly, we implemented a land change model that simulates the competition between multiple demands on land resources and the resulting changes in land systems. We parameterized the land change model CLUMondo with the identified land systems and location factors important for the spatial distribution of land systems in Laos. Finally, we developed and quantified three scenarios providing alternative developments of the drivers of land change in Laos informed by literature, trends in Laos and surrounding countries and expert knowledge. We explored with the model what trajectories of land system transitions evolve under the scenario assumptions.

### 2.2. Land Systems classification

A land systems classification was developed that characterizes the major land systems in Laos (including both smallholder and large agribusiness systems) as well as systems in transition from shifting cultivation towards permanent cultivation (Figure 1). The land systems capture the variety of different mosaics of agriculture and forest that are typical for many of the landscapes in Laos while making best use of the available data.

We obtained 16 land system classes after employing an expert based classification tree on four datasets (Table 1): land cover derived from satellite imagery, an agricultural census, maps of land concessions and leases, and hydrologic information of a topographic map updated with hydro-power reservoirs. To spatially characterize the land systems we chose to use a 2x2 km spatial resolution as this resolution allowed to capture the different components of land use mosaics on a landscape scale while making optimal use of the spatial resolution of the different data sources, the village-level census in particular. Out of the 16 land systems, nine smallholder systems were classified according to a matrix ordered by the agricultural intensity (shifting or permanent cultivation) on the y-axis and the share of forest coverage on the x-axis as illustrated in Figure 1. Despite the importance of shifting cultivation for Laos, no national statistics are

available explicitly reporting shifting cultivation (Heinimann et al., 2013). Upland rice is predominantly cultivated in shifting cultivation landscapes, hence, we chose it as a proxy to identify shifting cultivation systems. The ratio between the amount of upland rice area and the total agriculturally used area is computed to indicate to which degree upland rice dominates the production in the respective pixel. A low fraction of upland rice within the agriculturally used area is assumed to indicate a higher degree of permanent cultivation. Six versions of the classification using different classification thresholds for the two variables upland rice ratio and forest share were evaluated and validated by consulting 12 experts in natural resource management in Laos. The map with overall the highest rank in the expert-based validation was further used in this study.

**Table 1. Data integrated in land system classification**

Data set	Components used	Year	Geometry	Source
Land cover	rock	2010*	polygons	GOL 2010*
	water			
	urban	2002*		
	forest cover			
Maps of concessions and leases	mining tree plantations agricultural plantations	2012	polygons	Schönweger et al., 2012
Village level census of agriculture	upland rice agriculturally used land	2010/2011	village polygons	GOL 2012
Topographic maps	large rivers and lakes	1980	polygons	Russian topographic map 1:100k
	hydro power reservoirs	2012	polygons	World Bank 2010

Projection of all datasets: WGS84, UTM 48N.

\* land cover 2010 based on ALOS/AVNIR (10 meter resolution), land cover 2002 based on SPOT 4 (10 m resolution)

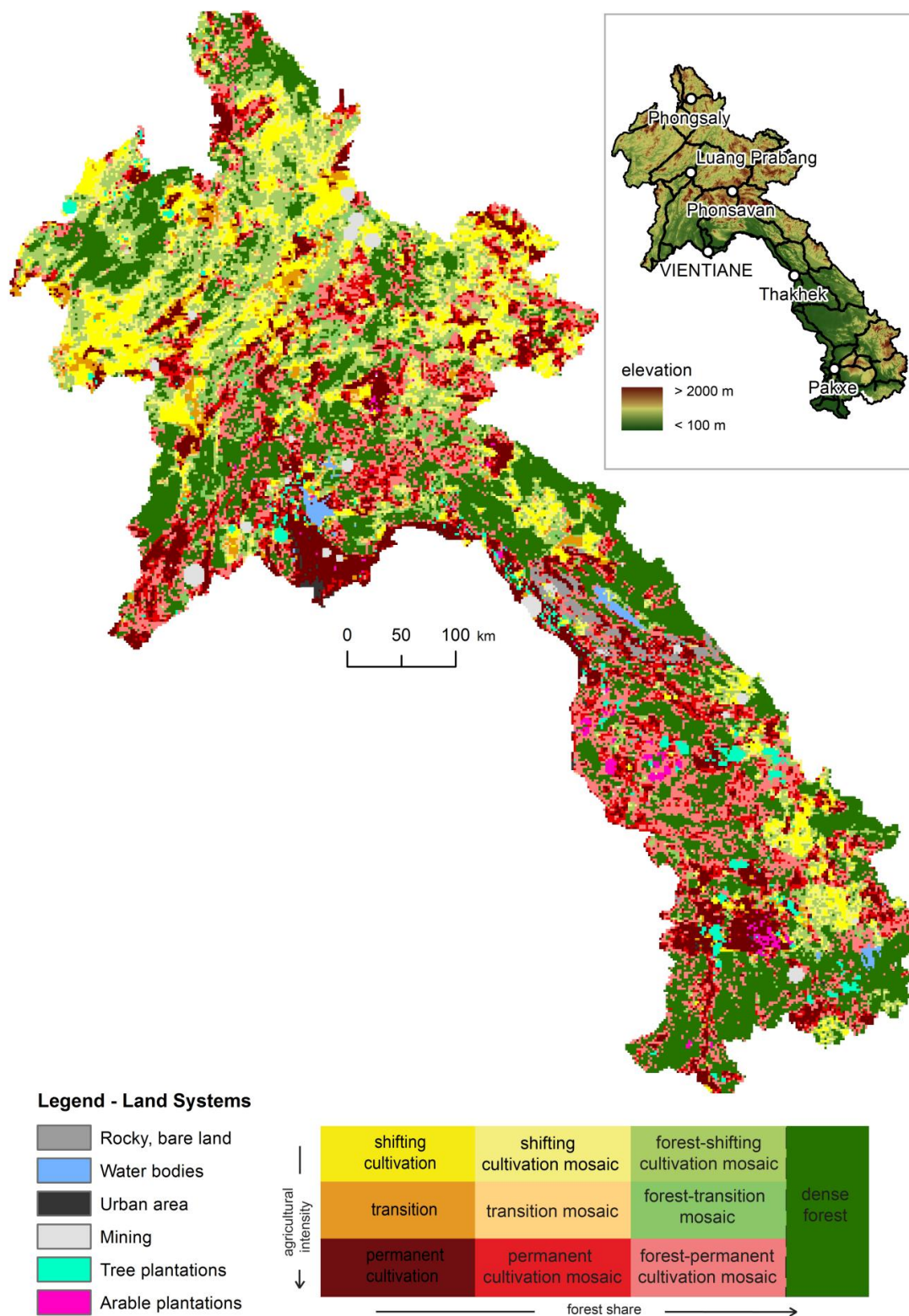


Figure 1. Land system matrix and classification map for 2010. Topographic map indicates elevation and main road network.

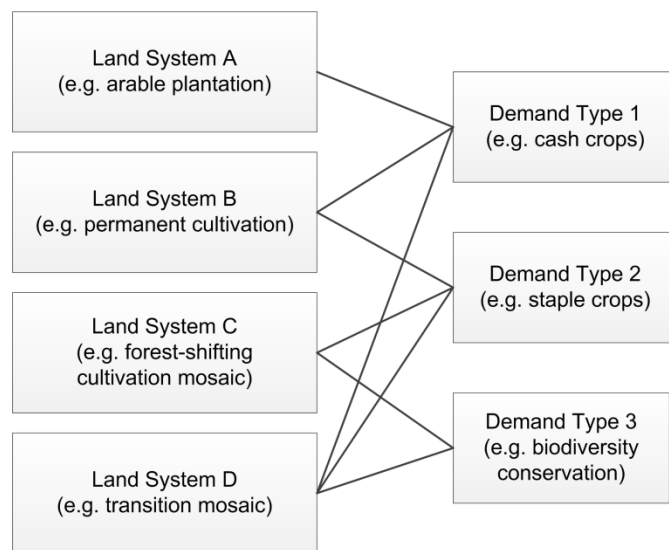


## 2.3. Land system model

### 2.3.1. Model description

We applied the CLUMondo land system model on a spatial resolution of 2x2 km to simulate scenarios of future land system transitions for Laos. This model is a spatial, multi-scale land-allocation model that, in contrast to other global and regional land use models, simulates land system change in response to multiple demands for goods and services (Van Asselen & Verburg, 2013). Each land system has a characteristic contribution to the supply of different goods and services (Figure 2). The model simulates land system changes in yearly time steps at pixel level. The changes are driven by demands for different goods and services. The model accounts for nationally aggregated demands that stem from domestic and international markets and matches it with local supply in the land systems at the pixel level while considering the location suitability for different land systems and the land system history of a location. As the transitions between different land systems in Laos are driven by multiple competing demands this model representation is very well suited for this specific application. The CLUMondo model was previously used for various global-level analyses e.g. (Eitelberg et al., 2014; Van Asselen & Verburg, 2013). For the first time we apply it on a national scale. The model makes changes to land systems in individual pixels until the goods and services, set as aggregate demands at the national level, are fulfilled by the cumulative contribution of all types of land systems in the country. In contrast to other models the CLUMondo model does not assume a hierarchy in allocating land systems, but rather addresses the different demands at the same time (Figure 2). Land systems are thus chosen in response to multiple demands, the differential suitability of the location for different land systems, restrictions on conversion at a certain location as set by the scenario (e.g. protected areas) or by the land system history (avoiding illogical transitions such as conversion of permanent cultivation to forest within one yearly time step). In this manner the model mimics the competition between different demands and different land systems that land use decision makers are faced with. For the allocation procedure the model requires several inputs. The model needs (1) the initial state of the study area (the land systems classification) and the typical contribution of different land systems to the provisioning of goods and services; (2) location suitability maps for each of the land systems (section 2.3.2); (3) total demand per year for different goods and services based on scenario assumptions (section 2.3.3), and (4) conversion settings that promote or restrict certain transitions from one into another land system. The latter input is specified in a conversion matrix indicating which land systems can, within each time step, be converted into what other land systems (Table A3 and A4 in Supplementary Information), or in what parts of the country conversions are prohibited, e.g. by including maps of National Protected Areas (DOF, 2011) (Figure A1 in Supplementary Information). While we are aware that land use conversion and deforestation might happen in protected areas despite regulations (Heino et al., 2015), we assume that they do not occur as a simplification in the model and due to lack of data to specify this process.

Some changes of land systems may take more time than single, yearly, modelling time-steps. Especially for systems containing major components of forest cover it was assumed that these must remain under the same land system for at least two years to allow expansion of forest vegetation before turning into a land system class with a considerably higher share of forest coverage. Due to a lack of historical land system data for the full study area we initiated the model with a randomized land use history. Sensitivity tests indicated that this approach results in different outcomes for single pixels upon different initializations, but the overall pattern and scenario results remain stable.



**Figure 2. Schematic representation of hypothetical relations between land systems and demand types in the CLUMondo model**

### 2.3.2. Land system suitability maps

Location suitability maps for all land systems are estimated using the current occurrence of the different land systems as an indicator of their preferred locations. For each land system the location suitability is described by relating the current spatial distribution of the land system to a set of environmental and socio-economic location factors using logistic regression models. These logistic regression models are then used to estimate, for each pixel, the probability of occurrence of a land system at that location as a proxy for the suitability.

As independent variables we used a set of socio-economic and biophysical location factors that are commonly used to explain the location of land use at regional scales and included specific factors important to the Lao context e.g. the distribution of ethno-linguistic families influencing land uses (Messerli et al., 2015). A total of 40 variables were considered, a full list and description is provided in Supplementary Information Table A1. A set of 21 explanatory factors remained after going through regression iterations and correlation analysis to reduce multi-collinearity, i.e. in case of correlation between independent variables (Pearson product-moment

correlation coefficient > 0.7) only one of the correlated variables was used. We applied a structured sampling method before carrying out the logistic regression ensuring that a) at least one pixel between each selected pixel was omitted from the sample, thus reducing spatial autocorrelation and b) balancing the presence and absence observations for each land system type. We measured the goodness of fit of logistic regression models with the area under the curve (AUC) criterion of the Receiver Operating Characteristic (ROC) (Swets, 1986). Table 2 provides details about the fitted regression models used for the suitability maps. Overall AUC values ranged between 0.681 and 0.991 indicating a modest to very good fit. Dominant factors determining the location suitability are accessibility and slope.

**Table 2. Logistic regression results per land system**

#	Land System	Independent/Explanatory variables	AUC
0	Rocky, bare land	-not estimated, considered static-	-
1	Water bodies	-not estimated, considered static-	-
2	Urban area	slope (-), pop.density(+), watprox_w2k (+)	0.991
3	Mining	-not estimated, considered static-	-
4	Tree plantations	temp (+), awc1, (+), dom_access (-), drain4 (-)	0.839
5	Arable plantations	drain4 (+), toc4(+), dom_access(-), slope(-)	0.901
6	Dense forest	access(+), popdens(-)	0.717
7	Permanent cultivation	popdens(+), lao-tai (+), access (-)	0.829
8	Permanent cultivationmosaic	popdens(-), slope(+), lao-tai(+), sino-tib(-), access(-)	0.715
9	Forest-permanent cult. mosaic	access(-), elev(-), lao-tai(+), drain4(+)	0.744
10	Transition	prec(-), dom_access(-), awc4(-), mn-khmer(-), popdens(-), s_clay(+), watprox_b2k (-)	0.706
11	Transition-mosaic	access(-), slope(+), precipitation(-), awc5(+), t_clay(-)	0.681
12	Forest-transition mosaic	int_access(-), slope(+), elev(+), s_clay(+)	0.692
13	Shifting cultivation	lao_tai(-), slope(+), t_gravel(+), access(-), prec (-), toc4(-)	0.712
14	Shifting cultivation mosaic	access (-), lao-tai(-), slope(+), awc5(+), prec(-)	0.730
15	Forest-shifting cultiv. mosaic	lao-tai (-), popdens(-), slope(+), temp (-)	0.740

\*Accessibility is measured by travel time. The higher the travel time, the less accessible.

### 2.3.3.Demand and supply of goods and services

We represent, depending on the scenario, four to six different goods and services that are supplied by the land systems and that are demanded by society in certain quantities. The demand for these different goods and services represent various pressures and incentives for the transition of land systems, depending on the scenario. The goods and services considered in this study include: 1) demand and supply of built-up area, being the area needed for housing, infrastructure, industry and services driven by population dynamics including migration and changing affluence; 2) demand and supply of staple crops forming the dominant part of local diets such as rice, which fulfils subsistence needs; 3) demand and supply of arable cash crops including both arable food and feed crops such as maize for domestic and international markets; 4) demand and supply of tree cash crops such as coffee and rubber, mostly linked to demand from international markets; 5) demand and supply of biodiversity conservation, represented by a high species

richness and abundance as facilitated by land management; 6) demand and supply of preserving cultural values linked to traditional land use, being the demand to protect and stimulate the continuation of traditional forms of agriculture related to the cultural heritage of the location and inhabitants, mostly being shifting cultivation systems in the context of Laos.

The demand and supply of biodiversity conservation is operationalized in two different ways depending on the scenario. Biodiversity conservation in Laos is conceptualized either as (i) conservation of primary forests in officially protected areas, and (ii) protection of agro-biodiversity in land system mosaics with mixed agro-ecosystems featuring high variety of genetic resources and species used for food, fodder, fibre, fuel and medicine (TABI, 2015).

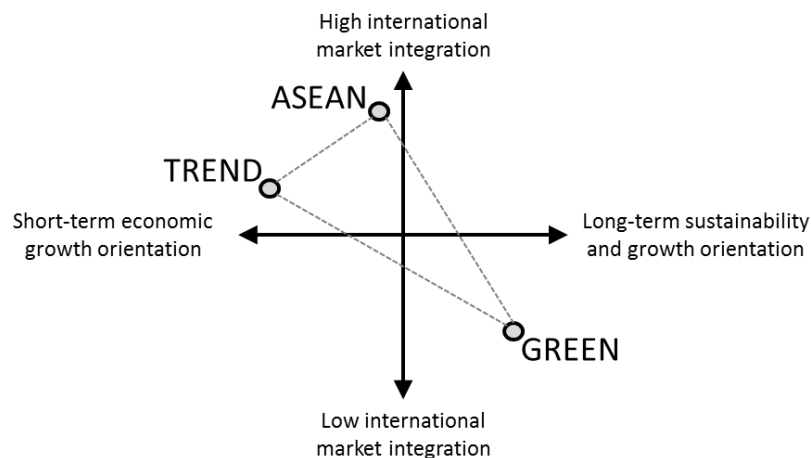
The supply of these goods and services by the different land systems is implemented by assigning a typical production of the good or service to each land system pixel (2x2 km). A land system is assumed to produce the same amount of goods and services independent of its location within the country. The supply of the different goods and services was based on expert estimates of what the land systems can provide in relation to each other (see Supplementary Information Table A2 for a full overview). For example a permanent cultivation land system provides higher amounts of arable cash crops but less biodiversity protection than a forest-permanent mosaic in the GREEN scenario given the larger share of cropping area within the land system. In estimating the supply of agricultural goods both the area of the land system dedicated to crop production and the intensity of agricultural management on that land were considered. All estimates were transferred into indices representing the proportional, relative quantities of production since absolute quantities in metric units were frequently not available. The change of demand for the different goods and services is determined for each of the scenarios using historic trends, developments in other countries and by assumptions that ensure consistency with the scenario storylines. All changes are relative to the 2010 situation in which the aggregate demand equals the supply of the goods and services of the land systems at that time.

## 2.4. Scenarios

### 2.4.1.Scenario storylines

We developed three scenarios for the time frame 2010-2030 that consider the main drivers and trends for land change identified in the literature and official statistics from Laos, its neighbouring countries and the larger region of Southeast Asia. Differential developments in market dynamics and land governance are two of the main drivers that may influence land system change in Laos (Castella et al., 2012) and the greater Mekong region (Rowcroft, 2008). Hence, we built our storylines along two axes of those drivers: a high vs. low international market integration and an orientation of government policies towards short term economic growth or long term sustainability and socio-economic growth (Figure 3). The TREND scenario forms the basic pathway derived from current trends from which the two alternative scenarios deviate in different directions. The TREND scenario follows on-going trends of the past decade

of market-liberalization and relatively low ambitions towards land governance for sustainability objectives. The scenario allows foreign investments through admission of concessions and leases for both arable and tree crop plantation agriculture. The scenario ASEAN even more prioritizes a high degree of market liberalization following trends in neighbouring countries. This scenario assumes high ambitions for international cooperation and market liberalization as main strategy to graduate from the UN ranking of least developed countries. Priorities of fast economic growth meet low structural capacity (institutional, technical, educational and legislative) when the ASEAN Economic Community (AEC, i.e. free flow of trade and investments within ASEAN) is implemented. This results in a high demand of cash crops for largely unprocessed export to ASEAN and WTO trade partners (Hirsch & Scurrah, 2015). To reach internationally agreed targets on reducing deforestation, shifting cultivators face restrictions in the use of dense forest areas. Furthermore, foreign investments into international forest conservation projects are implemented. In contrast, the GREEN scenario assumes a lower priority to market liberalization for large-scale land acquisitions and plantations and prioritizes land governance that empowers smallholders with ambitions towards sustainability, socio-economic resilience and low ecologic impact of economic growth. The main strategy to graduate from least developed country status is to support smallholders and invest in the structural capacity of institutions and landscape diversity. Forest within agricultural landscape mosaics is seen as a contribution to (agro-) biodiversity, a source of many ecosystem services and a part of agro-ecological intensification strategies. Shifting cultivation is not seen as a backward farming system but rather acknowledged as a traditional form of agriculture with cultural value for the countries' population and cultural diversity and heritage in general.



**Figure 3: Positioning of the scenarios towards main drivers of land system change**

#### 2.4.2. Scenario quantification

The scenario storylines are translated into model settings. The main model parameters influenced by the scenarios relate to the demand for goods and services (Table 3). In the TREND scenario

only the demand for built-up area, staple crops and arable and tree cash crops is considered. In the ASEAN scenario a demand for protecting biodiversity in forest habitats is added. The GREEN scenario also includes a demand for biodiversity conservation. In this scenario however, the demand for biodiversity conservation relates to both the conservation of biodiversity in natural habitats as well as in mosaic landscapes. Additionally, the GREEN scenario features a demand for cultural services provided by land systems with traditional forms of agriculture. Quantification of the demands was based on a variety of data such as statistical information, map comparison, expert consultation, official reports by NGOs and government bodies as well as the peer-reviewed literature.

The demand for built-up area is based on UN projections of average annual urbanization rates until 2030 in 5-year time steps (United Nations, 2014). Following this projection urbanization rates decline between 2010 and 2030 from ca. 3% to 1.3% per year. However, with increasing affluence the demand for built-up space per person increases steeply. Accounting for this we kept the growth in demand for built-up area throughout all scenarios at a yearly increase of 4.1%. All demands for staple crops, arable- and tree cash crops were established based on production growth rates in tonnes in FAO records (FAO-STAT, 2015). The rates of change of dominant crops in these categories, *paddy rice*, *maize* and *rubber*, were calculated for the years 2000 to 2010. Long-term statistical records of upland rice were unfortunately not available at an appropriate data quality and scale. Instead paddy rice served as a proxy for staple crop development with a production growth rate of ca. 40% between 2000 and 2010. Hybrid maize cropping has started in Laos around the year 2000 and experienced start-up production growth rates of +773% between 2000 and 2010 which are likely to decrease as FAO data of the neighbouring countries suggest (mean growth rates of about 180% per decade). Rubber production rates were unavailable for Laos. Therefore we computed 120% as the mean of the growth rates of the economies of the most influential neighbouring countries Thailand, Vietnam and mainland China (FAO-STAT, 2015), whose production growth rates have a longer history and are considered as an indicator for the development of tree cash crop cultivation in the coming years for Laos. We were aware of the fall of rubber prices in recent years. However, rubber is only a proxy for tree cash crops which include for example banana and coffee. Each tree cash crop may be subject to fluctuating market developments but as an aggregate category, we they experience an upwards trend as reflected in several cash crop booms (Friis, 2015). As compared to the TREND scenario, for the ASEAN scenario we increased the production growth rates for the cash crops following the storyline of free trade and investments under AEC from the year 2015 onwards. On the other hand, producing staple crops loses some significance due to increased availability of other (imported) food products on the markets. For the GREEN scenario slightly lower growth rates of cash crops as compared to the TREND scenario are assumed. The growth rate of staple crops is assumed to be similar given food security objectives.

310 **Table 3: Relative demand in 2030 as compared to 2010**

Scenario	built-up area	staple crops	arable cash crops	tree cash crops	biodiversity conservation	cultural services
TREND	223%	130%	236%	190%	n.a.	n.a.
ASEAN	223%	123%*	269%*	242%*	8% increase of dense forest	n.a.
GREEN	223%	130%	180%	180%	Max. 18% decrease of forest cover (total of dense forest and forest mosaic land systems)	Maintenance of minimally 50% of the 2010 area of traditional shifting cultivation land systems

311 \*in this scenario the rates until 2015 are similar to the TREND scenario; from 2016 onwards rates are modified indicating the  
 312 implementation of AEC treaties

313 Biodiversity conservation is conceptualized differently for the ASEAN and GREEN scenarios.  
 314 Under the ASEAN scenario, biodiversity protection is understood as conservation of primary  
 315 forest by implementing more protection zones and incentives to restore dense forest with  
 316 financial support of international donors and NGOs and to comply with internationally agreed  
 317 targets. Under the GREEN scenario the goal of biodiversity conservation is implemented in a  
 318 different manner: both dense forests and the agro-biodiverse land systems with a high forest  
 319 share, i.e. forest-permanent cultivation mosaics, forest-transition mosaics and forest-shifting  
 320 cultivation mosaics, are contributing to the biodiversity targets. All together the target is set at  
 321 losing less than 18% of the forest cover embedded in these land systems as compared to the 2010  
 322 situation. This is a rather ambitious target given the large increases in demand for staple and cash  
 323 crops that apply in this scenario.

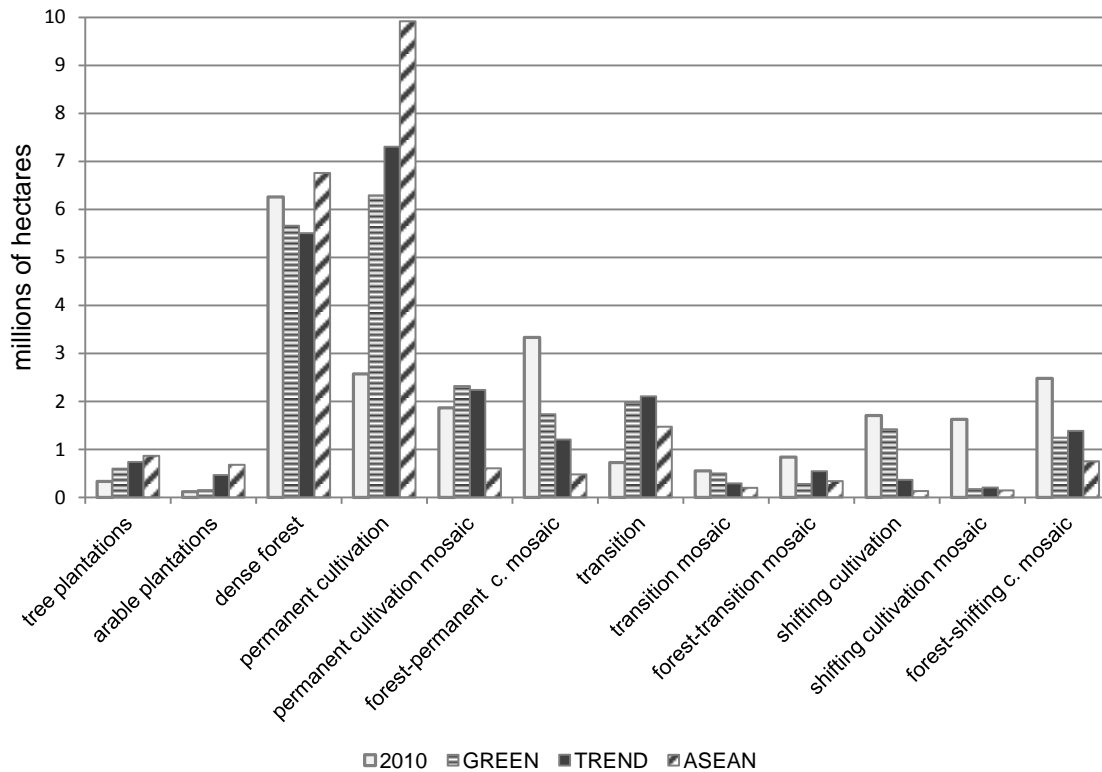
324 Cultural services provided by traditional land systems are only considered within the GREEN  
 325 scenario and the demand for these services represents the policies and subsidies to protect at least  
 326 half of the shifting cultivation landscapes present in 2010 to persist in 2030 as valuable cultural  
 327 asset and heritage for Laos. All three shifting cultivation land systems with different forest  
 328 coverages are considered to equally contribute to this.

### 329 3. Results

330 The simulation results for the different scenarios are presented in different ways in Figure 4 to 6.  
 331 In Figure 4 the absolute areas at the start and end of the scenario simulations are shown for the  
 332 different land systems. In 2010 the land system covering the largest area in the country is dense  
 333 forest. However, in all scenarios the largest area is occupied by permanent cultivation in 2030.  
 334 This does not necessarily mean that the area of dense forest is showing a large decrease. In both

the TREND and GREEN scenario the dense forest area shows a modest decrease while in the ASEAN scenario, as result of the demand for biodiversity conservation, the dense forest area increases. The ASEAN scenario is an illustration that the expansion of permanent cultivation under the scenario assumptions for Laos does not necessarily come at the cost of dense forest. In the ASEAN scenario permanent cultivation largely expands at the cost of different types of mosaic landscapes. Decreases are found in both the land systems permanent-mosaic and forest-permanent-mosaic as well as all three shifting cultivation land systems with different shares of forest cover. Where suitability for agriculture is high land is converted to permanent cultivation (by smallholders) or arable plantations or tree crop plantations. Where land suitability is lower for permanent cultivation, e.g. due to steep terrain, the mosaic landscapes are either abandoned and re-grow into dense forest or are used for tree plantations. The GREEN scenario shows a smaller increase in the permanent cultivation land system. Partly, this is a result of the lower demand for cash crops, but also a result of maintaining considerable areas covered by forest-agriculture mosaics and shifting cultivation systems. These systems are decreasing much less in area as compared to other scenarios as they contribute not only to the demand for staple crops, but also fulfil demand for biodiversity conservation (the forest mosaics) or cultural services (the shifting cultivation systems). At the same time, the lower demands for crop production in this scenario do not lead to saving more dense forest area as compared to the trend scenario. While plantations only cover a relatively small fraction of the total land area the increase is very strong, especially in the ASEAN scenario. For arable crop plantations there is hardly an increase in the GREEN scenario as in this scenario food crops are produced mainly in smallholder systems.





**Figure 4: Land area occupied by the different land systems for 2010 and in 2030 for the different scenarios**

Figure 5 shows the cumulative fraction of land occupied by the different land systems over time. Although most of the demands for goods and services were simulated linearly as time progresses, the land system changes show non-linear transitions. A noticeable outcome is the acceleration of the expansion of permanent cultivation during the second half of the simulation period. During the first period mostly gradual changes towards transition of arable agriculture in mosaics is occurring while only after these transitions, upon further increases in demand, the conversion to permanent cultivation land systems is occurring. This is much less visible in the GREEN scenario where the land systems permanent cultivation mosaic and forest-permanent cultivation mosaic decrease only slightly during the second part of the simulation period given the contributions of these systems towards both staple and cash crops as well as to biodiversity conservation targets.

Figure 6 provides insight in the spatial distributions of land system changes. The maps reveal that the different types of changes are not homogeneously spread across the country. In different parts of the country different trajectories are observed and these differ amongst the scenarios. In the northern part of Laos shifting cultivation with various fractions of forest covers is dominating. In all scenarios this is replaced, in different degrees, by permanent cultivation, mostly in the valleys while transitions systems (featuring both considerable shares of permanent

and shifting cultivation) are found on the slopes. In the TREND and ASEAN scenarios shifting cultivation systems only remain in the most remote locations, far from major towns and cities. In the central and southern part of Laos shifting cultivation land systems are only found at remote locations already in 2010 and almost disappears under all the scenarios. In 2010, in the southern and central part of the country, permanent cultivation land systems are found in the valleys and within mosaicked systems with high forest shares. Especially in the lowlands there is a large expansion of arable farming (permanent cultivation, arable and tree crop plantations) in all three scenarios. However, in the TREND and ASEAN scenarios we see that most of the permanent cultivation systems (smallholders) are replaced by plantation agriculture: arable plantations on the lowlands and high plateau (Bolaven) and tree plantations in the lowlands close to the Cambodian and Vietnamese borders. In the far south, dense forest is lost in the TREND and GREEN scenario, but retained in the ASEAN scenario. The uplands to the north and east of Vientiane shows the opposite trajectory that may be attributed to the assumption in the model on protected areas where no land use conversions are allowed. This results in all scenarios in an increase of dense forest cover whereas only permanent cultivation systems with different forest shares remain in the valleys.

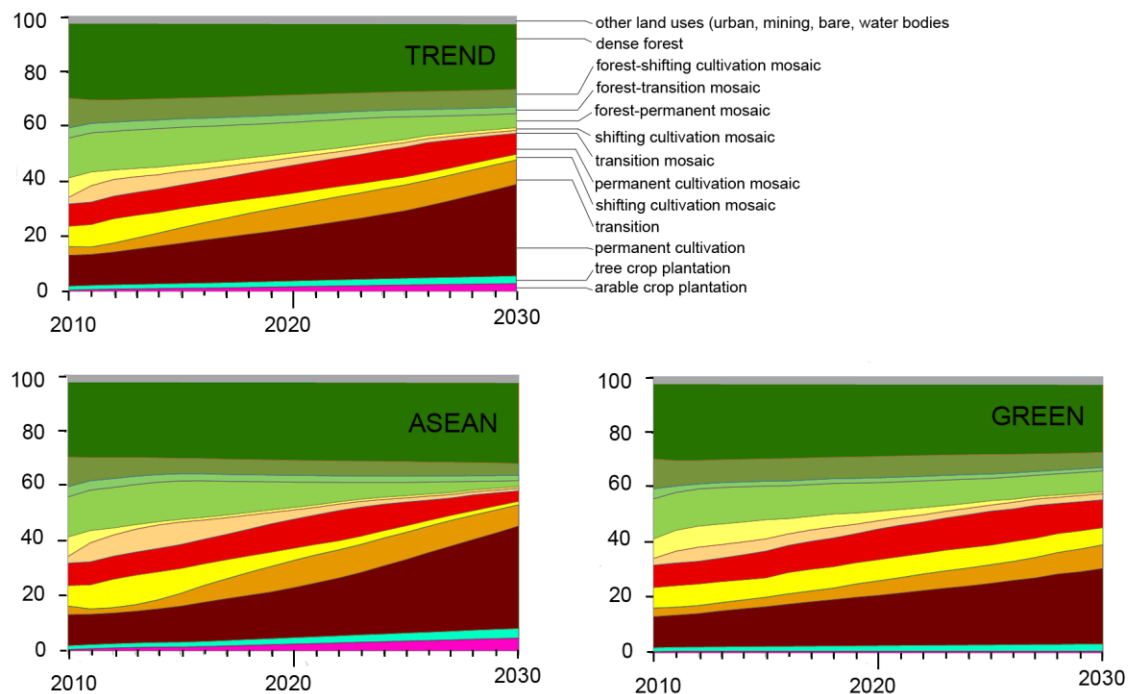
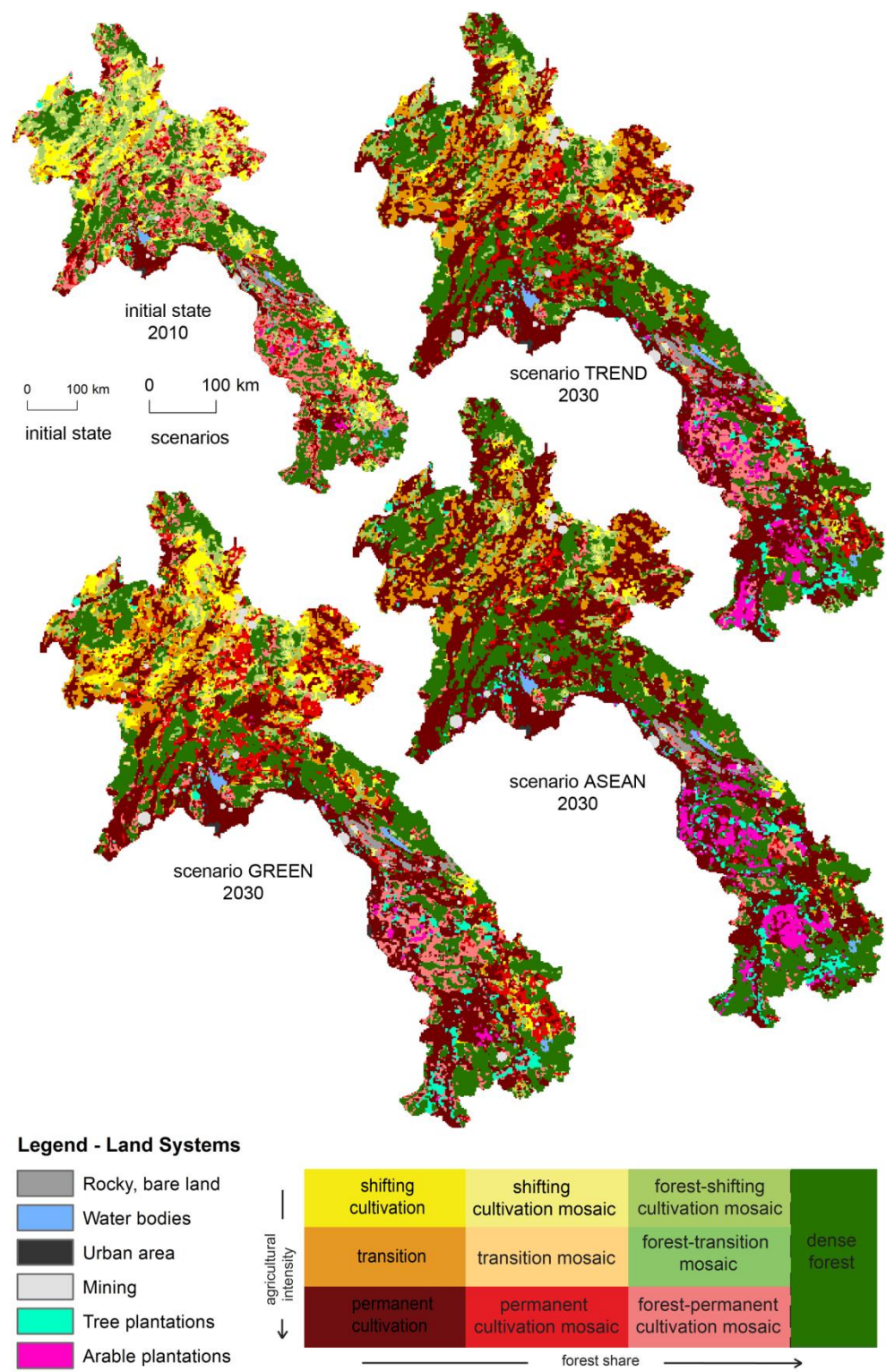


Figure 5. Simulated land system change over time, cumulative area in percent.



397 **Figure 6. Spatial distribution of land systems for initial year 2010 and the simulation results per scenario in year 2030**

## 4. Discussion

The model simulations presented in this paper address methodological challenges in simulating complex mosaic landscapes by simulating transitions in land systems rather than land cover. Based on this novel approach the scenarios simulated have sketched three different possible futures for land use in Laos. In this section we will discuss both the methodological aspects of this study as well as the results of our scenario analysis.

The majority of land change models only addresses land cover change. In highly heterogeneous landscapes such studies are of limited value as changes in the composition of land use mosaics are often rather subtle and missed when only changes in the dominant land cover are accounted for. Moreover, a land cover representation is unable to capture changes in land use systems such as farming system changes and the intensity of human management in the land use system. A land systems approach has many advantages, especially for a country like Laos with a mosaic of forest, smallholder (shifting and permanent cultivation) and large-scale agribusinesses (plantations). The simulations have shown that this representation makes it possible to capture pertinent changes such as the decline of shifting cultivation systems and the possible expansion of plantation agriculture replacing smallholder systems under certain scenario conditions. A novel feature of the modelling approach is the use of demands for different types of goods and services as drivers of land system change. In the scenarios developed in our study, the mix of goods and services demanded from land resources was specified in different ways in accordance to the storylines of the scenario. The different mixes of demand led to different land system changes as each land system is able to supply a different mix of goods and services. Changes in the bundle of goods and services demanded from the land are a common feature of socio-economic transitions and the development of society at large (Wolff et al., 2015). Societies no longer only demand food products from the land but also a wide range of other ecosystem services and protection of biodiversity. More different demand types than the ones used in this study could broaden the picture of the goods and services that land systems can provide and the multiple competing claims made on land resources that shape landscapes. Future scenarios could include also demands for other services, in particular regulating ecosystem services such as carbon sequestration and those regulating disaster risk such as flooding and landslides. However, such would largely increase the model complexity and may also be limited by available data. Often, different demands are competing for the same land. The CLUMondo model endogenously simulates the land system outcomes of such competing demand. The simulation outcomes for Laos show that these outcomes can vary strongly amongst scenarios. However, at the same time the impact on local land systems also strongly depend on the location characteristics, showing different trajectories of change in different parts of the country.

Validation of land change models is a difficult issue. Many land change models are never validated, especially those operating at large spatial scales (Prestele et al., 2016). This is mostly a consequence of the absence of consistent data for two historical time periods that can be used to

validate a model run over the same period. For smaller regions such data are more available and model performance is often tested (Pontius et al., 2008). In the case of Laos we face similar problems of obtaining consistent data for two time periods. The initial land system classification was elaborated based on best and most recent available data. No suitable land cover or land use data were available for another year to allow a comparison on the national scale. Even if such data was available to enable a model validation on past land system change, the processes that determine land systems in Laos have changed considerably and historic processes of change are very different from those addressed in the scenarios. The transitions in land systems lead to land system configurations unprecedented in Laos and validity of the model for historic conditions does not necessarily mean a valid model for these very different future conditions. This is a general problem for models exploring socio-ecological transitions or regime shifts (Verburg et al., 2015). One way to test model validity is to compare the model outcomes with situations in neighbouring countries that have faced similar processes of change. Müller et al. (2014) present results of fieldwork measuring changes in similar land systems, characterized by a large proportion of mosaic land cover and shifting cultivation systems, in South-East Asia. Their results from Indonesia, Vietnam and Southern China show, at case-study level, different trajectories upon a decrease in shifting cultivation during a 30-year period. In some cases, shifting cultivation is replaced by small areas of permanent cropping with re-growth of secondary forest at other locations. In other cases, shifting cultivation areas are taken over by plantation crops. The differences between these trajectories are explained by differences in the drivers and subtle perturbations in the local conditions or conjuncture. The different trajectories found by Müller et al. (2014) across case-studies in South-East Asia are also found within our simulations results, at different places within Laos and with a different importance within the different scenarios. Although comparison of these case study results with simulation results is difficult it indicates that the model is capable of replicating the regime shifts described for the region.

The scenarios for future land systems in Laos indicate that differences in demand and societal priorities lead to very different land system outcomes dependent on location within the country. Müller et al. (2014) argue that modelling land use regime shifts is limited by the difficulty to predict the timing, nature and amount of changes in socio-economic and political drivers of land change. Our study shows that land system models can be used to explore the occurrence of such regime shifts under a set of scenario assumptions. By doing so, such modelling results can stimulate discussions on the trade-offs between satisfying human needs, the biosphere and the loss of diversity (Messerli et al., 2015).

## 5. Conclusion

Land change is not a continuous or gradual process. In many cases land use change reflects larger, sometimes discrete, changes in society and development at large. This is particularly true in the mountainous areas of South-East Asia where many countries have seen regime-shifts in land systems. Laos did not yet experience as large transitions in land systems as other countries in the region (e.g. Vietnam). We developed three scenarios to explore potential future changes. All three scenarios illustrate large transitions in land systems. At the same time, the scenarios show that the orientation of land governance and the priority given to other services from land systems besides agricultural production impact on the land use futures of the country. The land system approach facilitates this by going beyond land cover to land systems representations as these better reflect the socio-economic and land use realities. Irrespective of uncertainty in data and model, such scenarios can help to discuss what land use futures are wished for in Laos, and what conditions would be needed to achieve these. The novel modelling approach applied in this paper allows addressing these issues in a way that accounts for land use as being part of a socio-ecological system rather than only addressing its land cover appearance.

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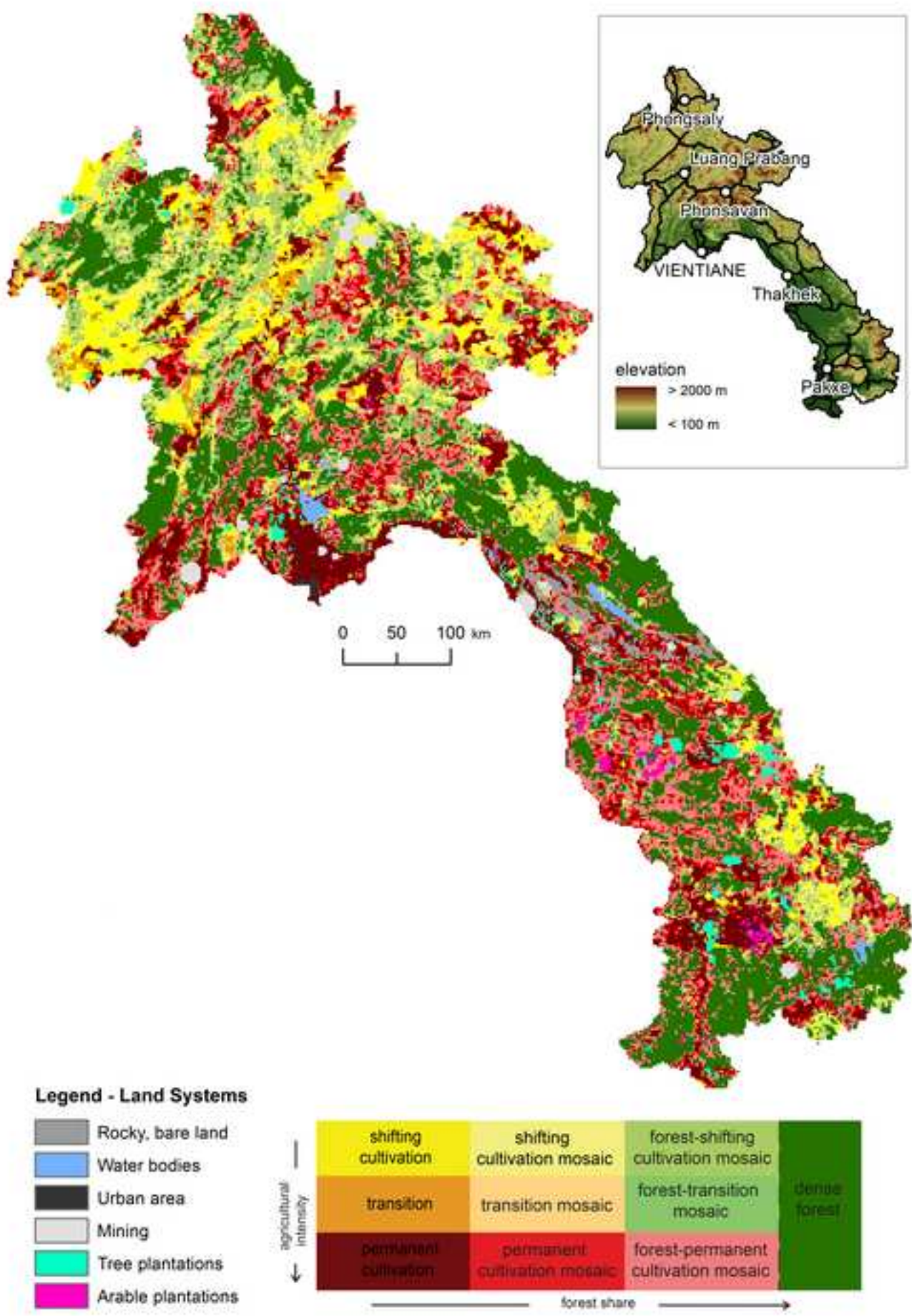
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## Highlights

- Land systems rather than land cover represented and simulated
- Multiple demands towards land systems endogenously modelled
- Effects of various aspects of market integration and governance on land tested
- National scale exploration of three scenarios from 2010-2030 in the Lao PDR

Figure 1  
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**Figure 2**  
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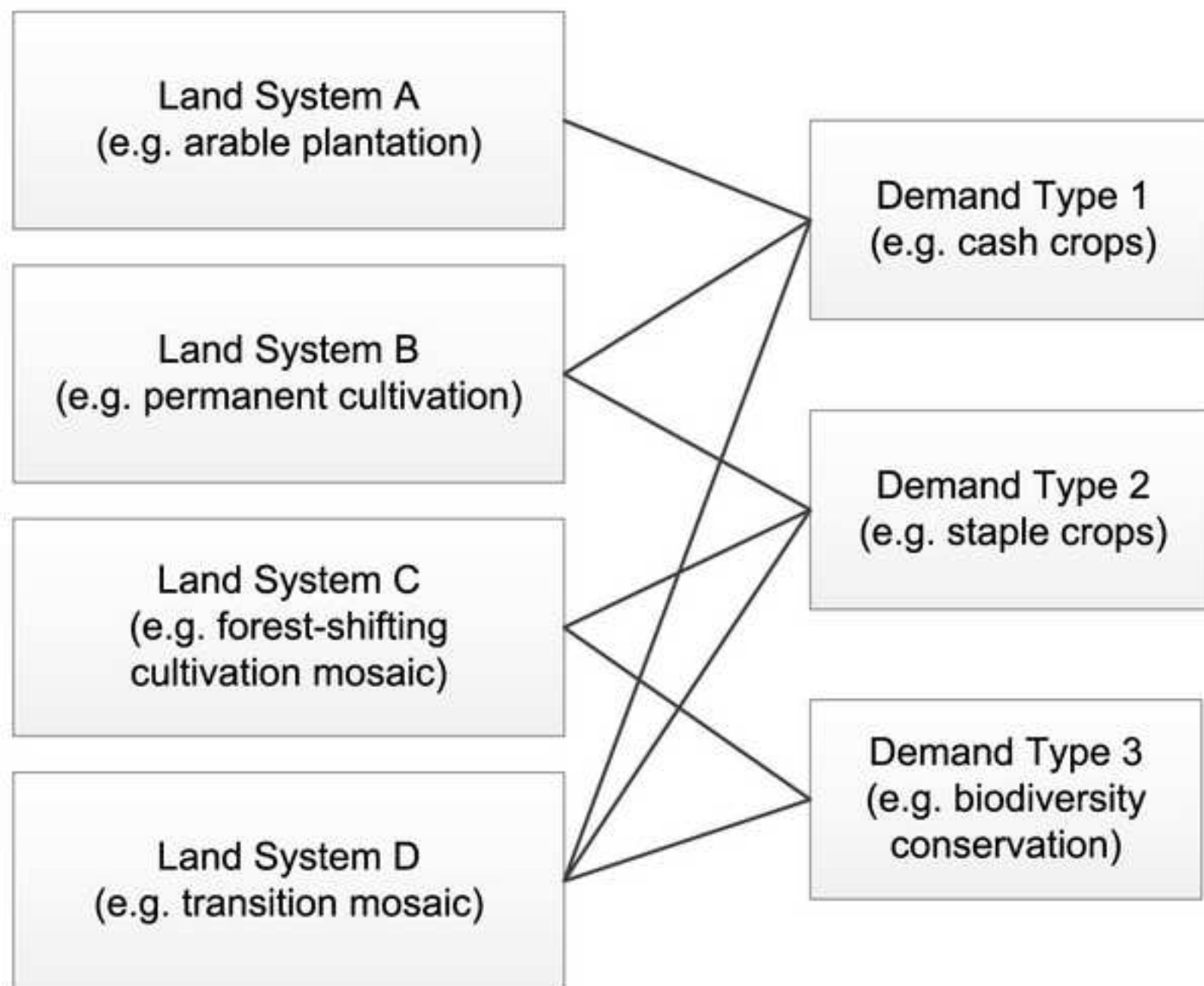


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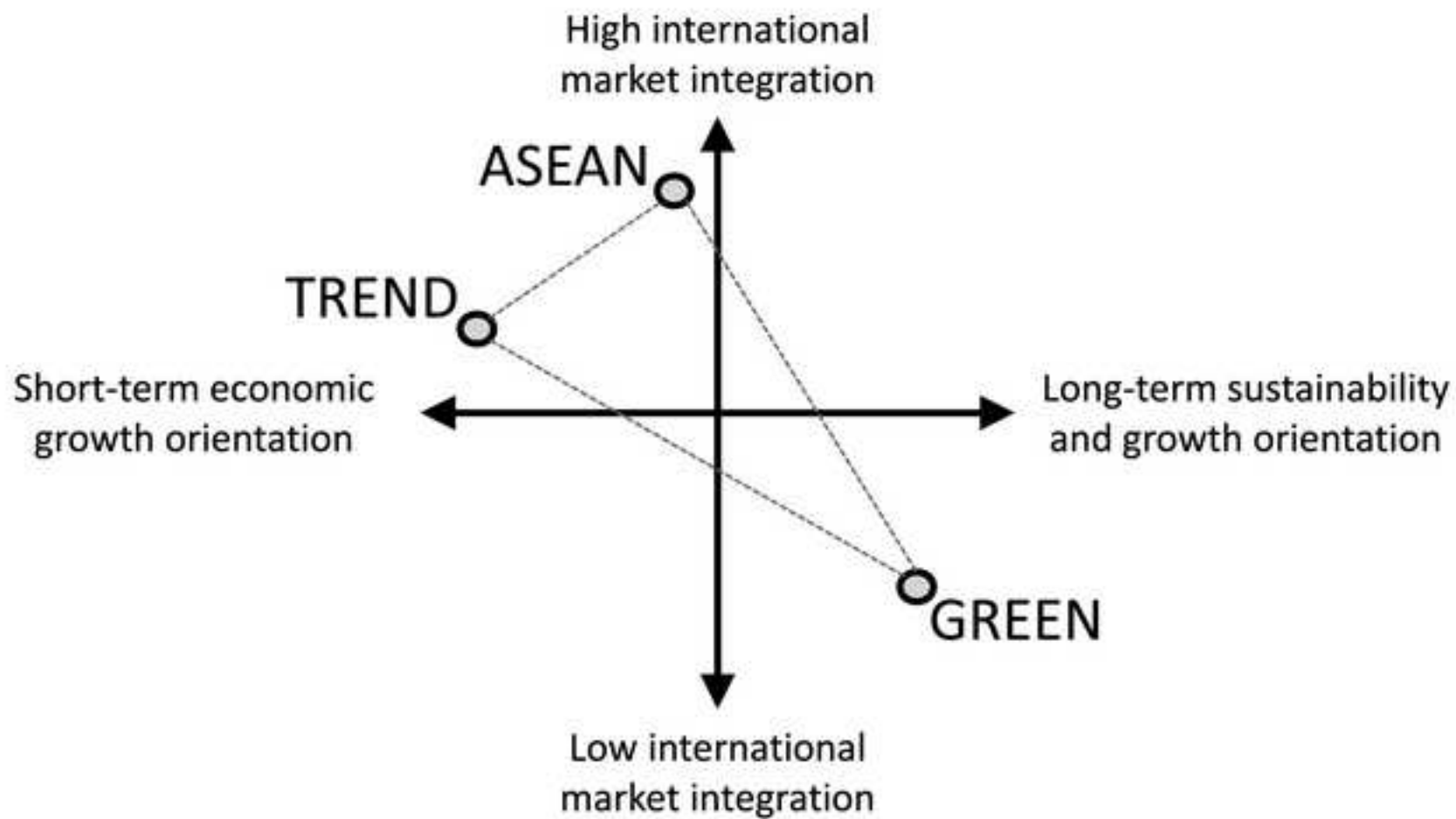
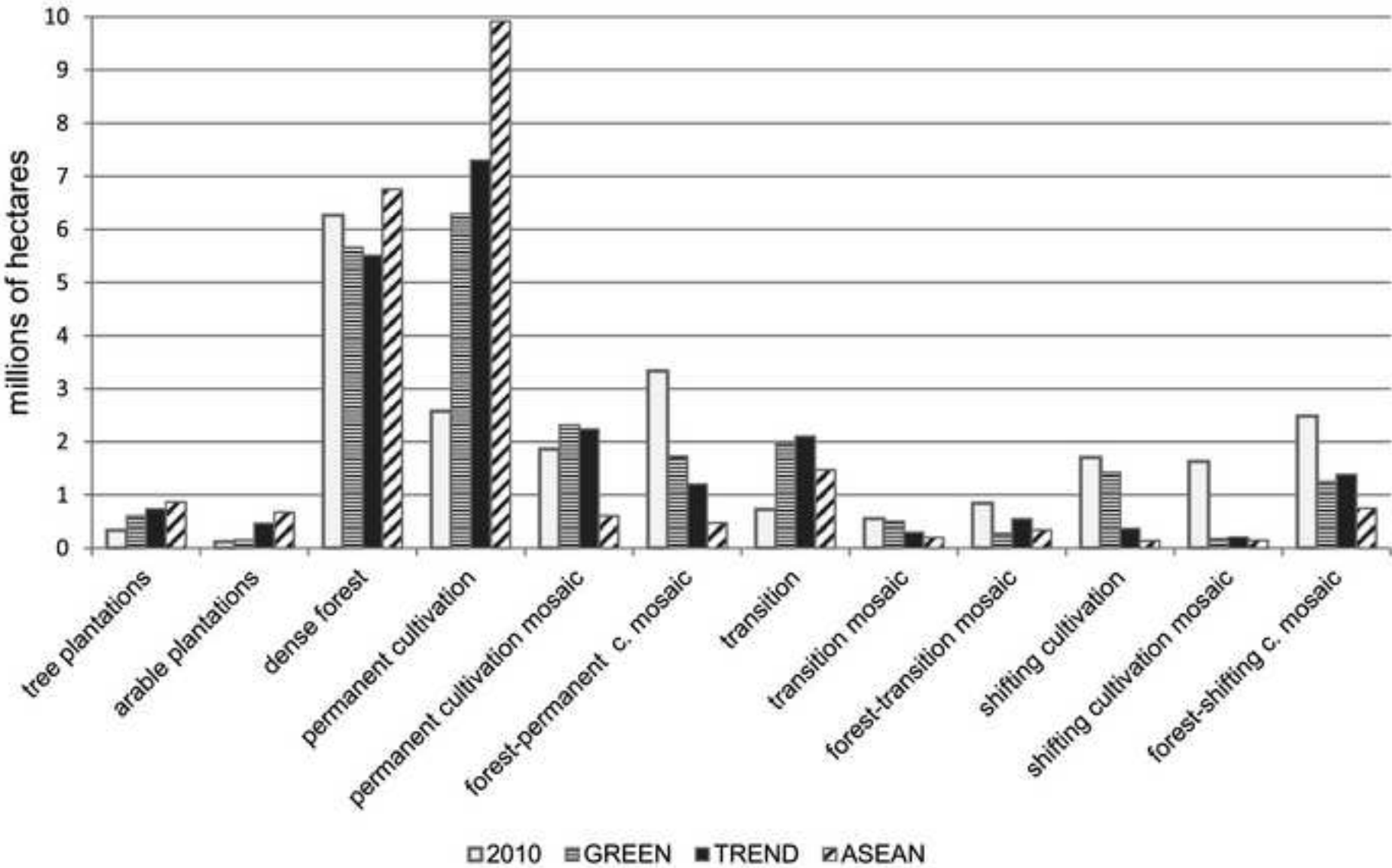


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**Figure 5**  
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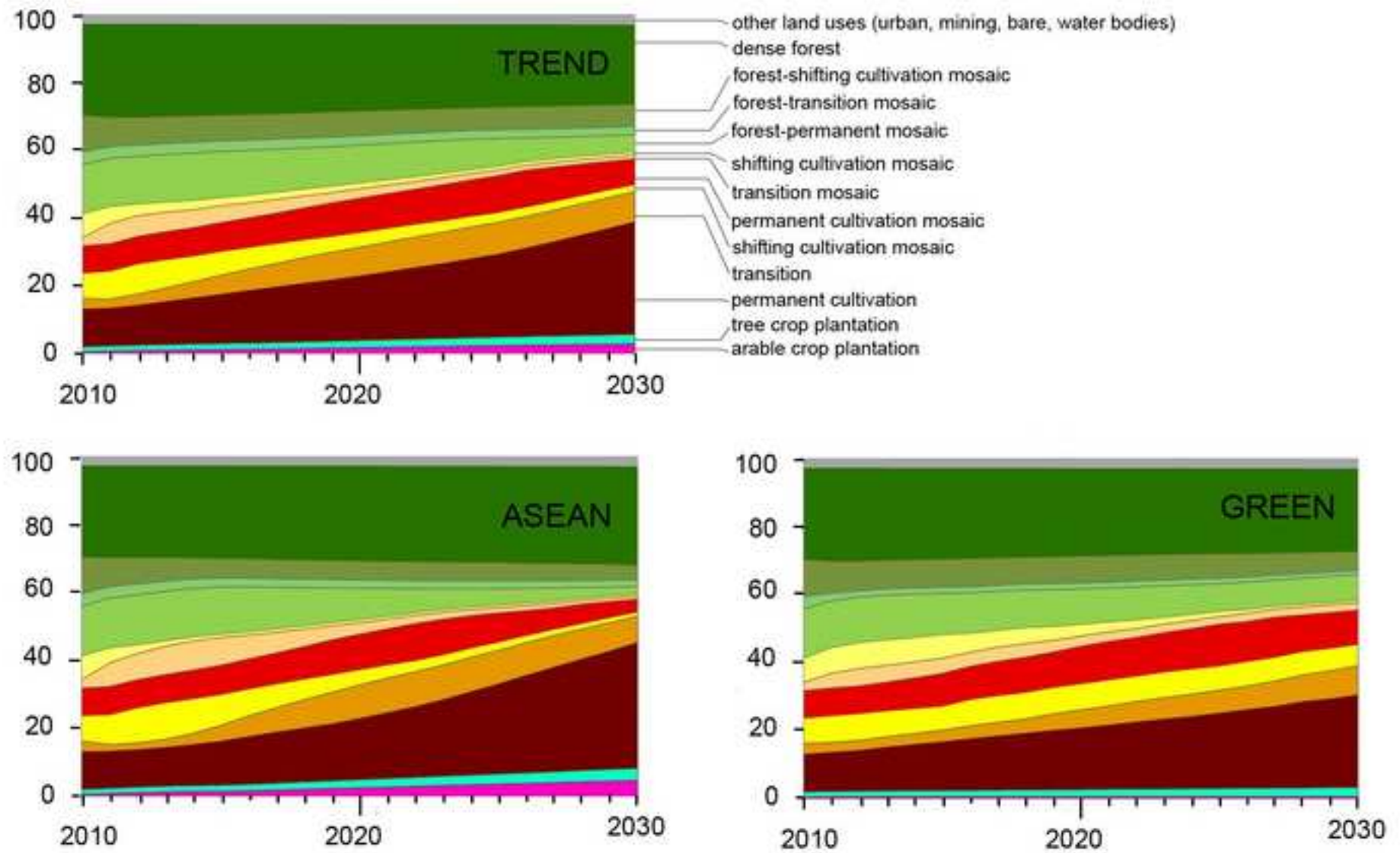




Figure 6  
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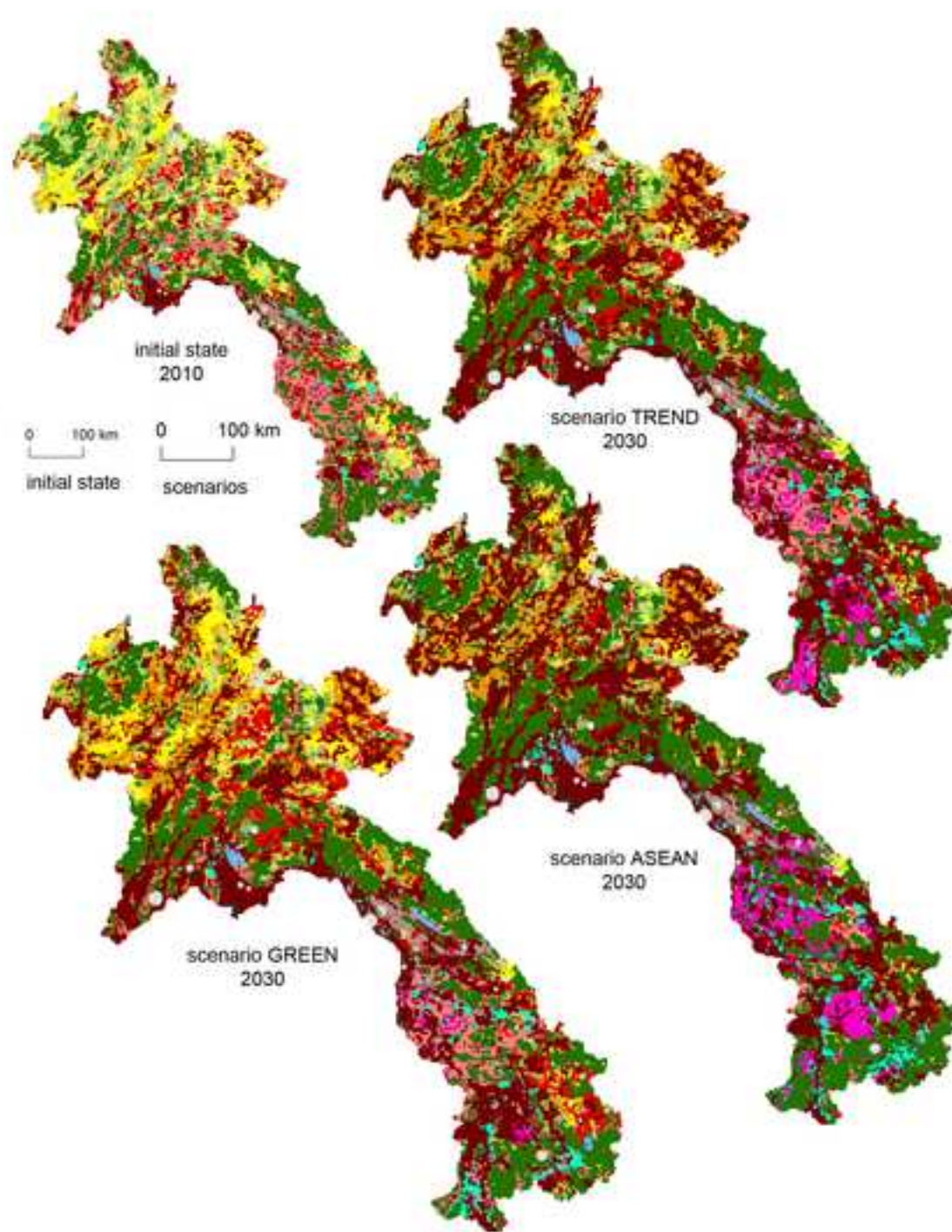
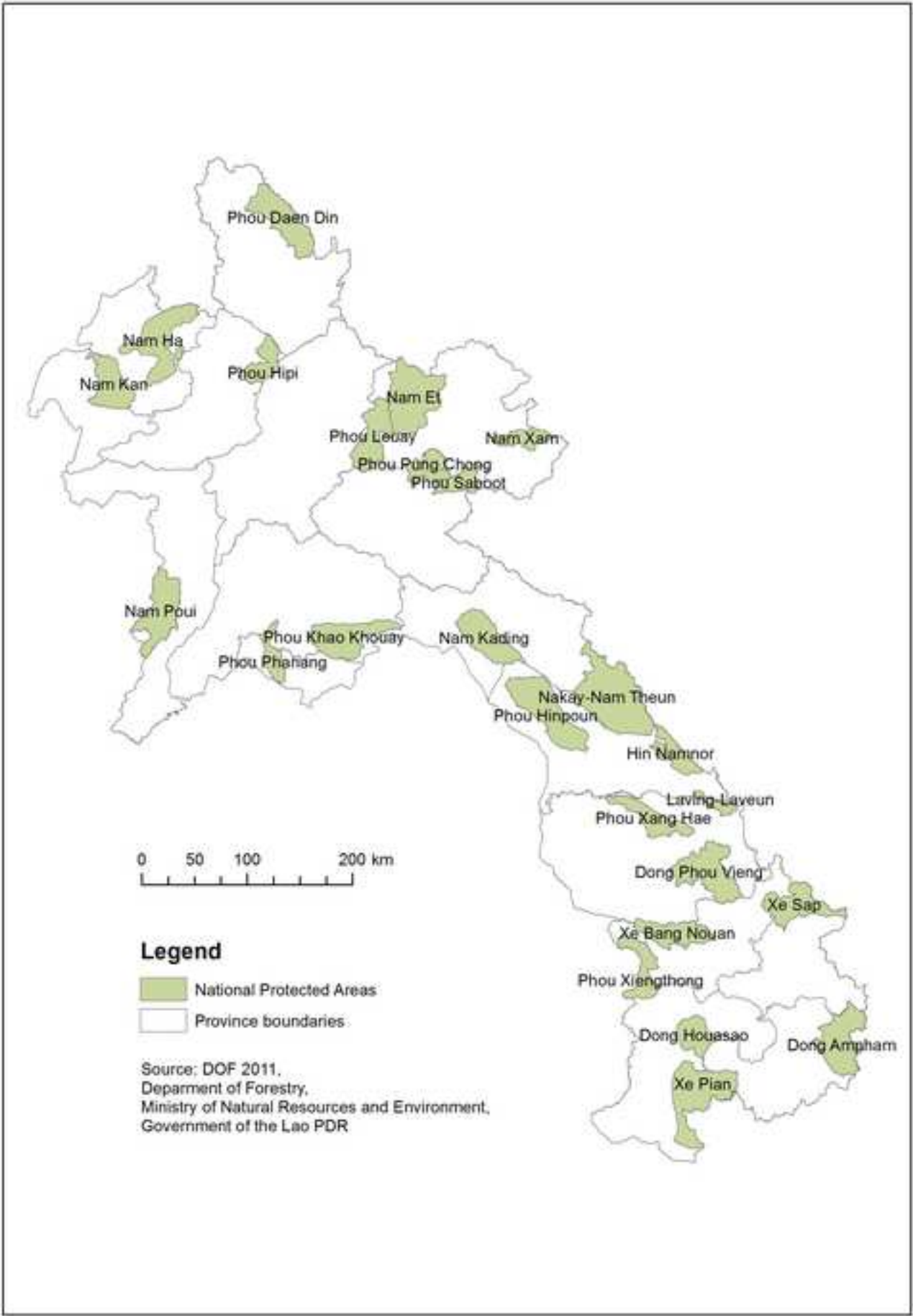


Figure A.1 (also in Appendix)  
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